Letters to the Editor

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NOTES ON POINTS IN SOME OF THIS WEEK'S LETTERS APPEAR ON P. 72.

Disintegration by Slow Neutrons

FERMI and his collaborators[1] have reported that neutrons slowed down by collisions in substances containing hydrogen are captured by many nuclei very much more frequently than are fast neutrons. In the cases reported, the process is one of pure capture, resulting in the formation of a higher isotope. It is to be expected that slow neutrons may cause a nuclear transformation with the emission of heavy particles if energy can be released in the process. The probability of such a reaction will depend on the mutual kinetic energy and potential barrier of the resulting particles, and may be large when these quantities are of the same order of magnitude; this can in general only be expected for elements of low atomic number.

We have examined some of the lighter elements for such transformations. The general procedure was as follows. The element under examination was enclosed, as target or as gas, in an ionisation chamber connected to an amplifier and oscillograph and exposed to the bombardment of neutrons from a radon-beryllium source. A small number of ionisation 'kicks' was always observed, due mainly to recoil particles. The source and chamber were then surrounded by paraffin wax, thus exposing the target or gas to the bombardment of slow neutrons. In some cases, notably those of lithium and boron, a very large increase in the number of 'kicks' was observed, indicating that a nuclear transformation was taking place.

With lithium, the kicks observed were of two kinds, one due to doubly charged particles and one to singly charged particles. By covering the lithium target with aluminium foils we found that the singly charged particles had a maximum range of about 5·5 cm. in air, and that the range of the doubly charged particles was less than 1·5 cm. This suggests that the particles arise from the reaction

$$_3\mathrm{Li}^6 + {}_0n^1 \longrightarrow {}_2\mathrm{He}^4 + {}_1\mathrm{H}^3.$$

From the masses of the nuclei concerned, an energy release of about 5 million electron volts is expected, and a range of the H^3 particle which agrees well with that observed.

In the case of boron, the majority of the particles appear to be doubly charged and to have ranges less than 5 mm. in air. The only reaction which appears to fit the facts is

$$_5\mathrm{B}^{10} + {}_0n^1 \longrightarrow {}_2\mathrm{He}^4 + {}_2\mathrm{He}^4 + {}_1\mathrm{H}^3.$$

A small but definite effect has been observed with nitrogen, and a rather doubtful effect with beryllium.

The most interesting feature of these reactions is their very high probability. The cross-section[2] for capture of a slow neutron by Li^6 or B^{10} appears to be of the order of 10^{-21} sq. cm., a magnitude which suggests that there is an attractive force between a nucleus and a neutron at relatively large distances. The above reactions afford a convenient and sensitive means for detecting the presence of slow neutrons.

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[1] Fermi, Amaldi, Pontecorvo, Rasetti and Segrè, *Ricerca Scientifica*, V, 2, 282; 1934.
[2] cf. Fermi, Pontecorvo, Rasetti, *ibid.*, 380; 1934.

Metaplasia of Uterine Epithelium Produced by Chronic Œstrin Administration

THE synthesis of polycyclic compounds possessing both œstrogenic and carcinogenic properties[1], the finding of considerable amounts of œstrin in cancerous tissue[2] and in the blood of tumour-bearing male mice[3], and the demonstration in various ways of a correlation between the amount of œstrin present in the body and the incidence of spontaneous mammary carcinoma (in susceptible strains of mice)[4] have led many students to suspect an interrelationship between epithelial growths and the female sex hormone. Metaplasia from columnar to stratified epithelium in the seminal vesicles and coagulating glands of male mice and rats treated with œstrin has been noted[5,6,7], but analogous effects in female animals have not been reported. Overholser and Allen[8] have found that treatment with œstrin and corpus luteum hormone enhances the atypical epithelium proliferation produced by traumatisation of the cervix uteri in monkeys; but since this proliferation occurred in a region in which squamous epithelium is normally present, it cannot be said whether metaplasia occurred or not.

Recently, a series of experiments were planned with the view of determining to what extent the 'antihormone' theory[9] might be found applicable. In one of these a group of eight female castrates were injected daily intraperitoneally with 30–60 γ of œstrone in oil (crystalline folliculin, kindly supplied by Dr. Girard) over a period of ten weeks. The mammary glands showed marked duct proliferation with some formation of alveoli; the degree of development was the same in biopsy specimens removed two weeks after the beginning of treatment as at the end of the experiment. Biopsy specimens also showed that the uterus and vagina preserved their œstrous development throughout the whole period. The experiment therefore confirmed the statement of D'Amour[10], that loss of sensitivity to œstrin does not occur. But when the animals were killed after ten weeks treatment, histological examination of their uteri showed in four cases a more or less complete metaplasia of the cylindrical secretory epithelium into a stratified squamous epithelium with cornification, from which irregular buds penetrated deep into the stroma.

In another experiment, 0·1–0·3 c.c. of 0·1 per cent œstrone in corn oil was placed in one horn of the uterus of each of six adult castrate female rats, escape of the oil being prevented by ligation of the uterus; the animals had previously been treated with moderate doses of œstrone intraperitoneally in order to distend the uteri. The animals were killed on the fourth day after filling the uterus; the œstrin-treated horn showed signs of commencing metaplasia in three cases and complete metaplasia to stratified squamous epithelium in one case.

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[1] Cook, Dodds, Hewett and Lawson, *Proc. Roy. Soc.*, B, **114**, 272; 1934.
[2] Loewe Raudenbusch and Voss, *Biochem. Z.*, **249**, 443; 1932.
[3] Engel, *Z. Krebsforschg.*, **34**, 658; 1931.
[4] Lacassagne, *C.R.*, **195**, 630; 1932.
[5] De Jongh, *Acta Brevia Neerl.*, **3**, 112; 1933.
[6] Lacassagne, *C.R. Soc. Biol.*, **112**, 590; 1933.
[7] Burrows and Kennaway, *Amer. J. Cancer*, **20**, 48; 1934.
[8] Overholser and Allen, *Proc. Soc. Exp. Biol. N.Y.*, **30**, 1323; 1933.
[9] Collip, *J. Mount Sinai Hosp.*, **1**, 28; 1934. Collip, *Annals Internal Med.*, **8**, 10; 1934.
[10] D' Amour, Dumont and Gustavson, *Proc. Soc. Exp. Biol., N.Y.*, **32**, 192; 1934.

Production of Electron-Positron Pairs

THE production of a pair of positive and negative electrons by two photons was one of the consequences of his theory of the electron first considered by Dirac. This effect is essentially at the basis of all pair production phenomena, and it may be of interest to point out that from the formula for it, recently given by Breit and Wheeler[1], we may readily deduce, to a certain approximation, the probabilities for the production of pairs by high-energy photons and electrons in the field of an atomic nucleus. The correlation of these effects depends on the fact that for an observer moving relative to a nucleus with a velocity approaching that of light, the field of the nucleus is approximately equivalent to a radiation field. In the region effective for producing pairs—at distances from the nucleus of the order of and greater than $\hbar/mc$—the nuclear field corresponds, for an observer travelling with velocity v, to a distribution of photons the number of which in the frequency interval $d\nu$ is given by

$$N(\nu)d\nu = (2/\pi)\alpha Z^2 \log (g\gamma mc^2/h\nu)\, d\nu/\nu \qquad (1)$$
$$\alpha = e^2/\hbar c, \quad \gamma = (1 - v^2/c^2)^{-1/2}, \quad g \sim 1.$$

The cross-section, σ, for pair-production by a photon, $h\nu$, of energy ξmc^2, $\xi \gg 1$, is now obtained by considering its interaction with the photons, which, according to (1), represent the nuclear field. For a system S', moving with the incident photon with a velocity such that the energy of the photon is reduced from ξmc^2 to mc^2, the expression for σ thus obtained is

$$\sigma = \int_{h\nu = mc^2}^{h\nu \sim \xi mc^2} \sigma(\nu) \times (2/\pi)\, \alpha Z^2 \log (g\xi\, mc^2/h\nu)\, d\nu/\nu. \quad (2)$$

$\sigma(\nu)$ is the cross-section for pair-production by a photon of energy $h\nu$ and a photon of energy mc^2, travelling in opposite directions. The second factor is the number of virtual photons in the nuclear field with frequency in the range $d\nu$. On substituting for $\sigma(\nu)$ the expression given by Breit and Wheeler and integrating, this gives

$$\sigma = (28/9)\, \alpha Z^2\, (e^2/mc^2)^2 \log g\xi, \qquad (3)$$

which agrees with the result obtained by Heitler and Sauter by direct application of Dirac's theory. In this formula, and also the other formulæ given in this note, g is used to denote a numerical factor of the order of unity. Its exact value in the different cases cannot be derived by the present method and this represents the degree of approximation involved.

The production of pairs in collisions between two electric particles may be deduced in a similar way, either by replacing the field of both particles by radiation and using the Breit-Wheeler formula, or only the field of one and using the Heitler-Sauter-Bethe[2] formula. Adopting the second procedure we obtain, as the cross-section for the production of a pair, of energy between εmc^2 and $(\varepsilon + d\varepsilon)mc^2$ (including energy of mass), by an electron of energy ξmc^2, in the field of a nucleus, Ze,

$$\sigma(\varepsilon)d\varepsilon = (28/9)\, \alpha Z^2\, (e^2/mc^2)^2 \log\, (0{\cdot}15\varepsilon) \times (2/\pi)\, \alpha \log\, (g\xi/\varepsilon)\, d\varepsilon/\varepsilon, \qquad (4)$$

being simply the product of the Heitler-Sauter-Bethe formula and (1) (remembering that for an electron $Z = 1$). If $\varepsilon \gg 137Z^{-1/3}$, then in the first logarithmic term in (4) we must replace $0{\cdot}15\varepsilon$ by $179Z^{-1/3}$, on account of the effect of shielding.

The cross-section for the production of a pair of any energy, according to (4), is

$$\sigma = \int_2^{\sim\xi} \sigma(\varepsilon)d\varepsilon = (28/27\pi)\, \alpha^2 Z^2 (e^2/mc^2)^2 (\log g\xi)^3. \qquad (5)^*$$

Regarding the pair-production by a high energy photon, it is of interest that, in the system S', to which (2) explicitly refers, the pair-production is practically all due to the interaction of photons of energy of the order of mc^2. This results from the fairly rapid convergence of the integral in (2), the integrand being asymptotically proportional to ν^{-2}. This is quite analogous to the state of affairs in the problem of radiative collisions, where the use of the Klein-Nishina scattering formula on the same lines as the present use of the Breit-Wheeler formula, shows that the emission of radiation by a high energy electron in a nuclear field may be reduced to the scattering of radiation of quantum energy[3] $\sim mc^2$. Both the pair-production formula and the radiative formula have thus a very simple theoretical basis.

A fuller discussion of the contents of this note and of other effects of charged particles which may be correlated with radiation effects will shortly be published in the *Proceedings* of the Danish Academy.

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* (4) gives only the order of magnitude of $\sigma(\varepsilon)$ if $\varepsilon \sim 1$ or $\varepsilon \sim \xi$. These regions of ε are, however, not important to the integrated cross-section. It might be remarked that (5) is in harmony with the results for pair-production by 2 particles obtained by Landau and Lifschitz by direct application of Dirac's theory, in so far as their calculations are published (NATURE, **134**, 109, July 21, 1934).

[1] *Phys. Rev.*, **45**, 766; 1934. The value given must be divided by 4 for use in the present connexion, according to a communication from the authors.
[2] *Proc. Roy. Soc.*, A., **146**, 83; 1934.
[3] Compare v. Weiszäcker, *Z. Phys.*, **88**, 612; 1934; and E. J. Williams, *Phys. Rev.*, **45**, 729; 1934.